Brief Review of Current Technology for Control of Phosphorus Discharge in Effluents from Three Kraft Pulp Mills on the Androscoggin River

prepared for

State of Maine
Department of Environmental Protection

by

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1. Summary

1.1 Overview

Technology available to reduce discharge of phosphorus is reviewed, in the context of the three pulp mills discharging to the Androscoggin River in Maine and New Hampshire.

Based on an analysis of the conditions in the Androscoggin River, Mitnik (2003) suggests that it will be necessary to reduce the phosphorous discharges from these three kraft mills by approximately two-thirds, which would require their reducing current discharges to approximately 50 g/ton pulp produced, or 33 g/ton paper. This is lower than the discharge from most kraft mills in the world, but still about double that attained by several mills which operate with similar pulp, paper making and waste treatment processes.

Current phosphorus discharges from the mills of interest, as shown in Table 1 below are typical of the range seen in US mills, although a few mills operate with much lower values.

Table 1 Effluent discharges from pulp and paper mills on the Androscoggin River

Mill	Effluent flow MGD	m^3/t	Phosphorus mg/L	Phosphorus lbs/day	Phosphorus g/ton pulp
Berlin, NH (Burgess mill)	16	111	2.6	350	250
Berlin, NH (Cascade mill)	10	69	0.5 ??	50 ??	
Rumford, ME	31	92	0.7	200	95
Jay, ME	46	137	0.8	270	135

Data shown for discharges is the most recent available to the authors. It is indicative of current discharges.
There were few data available on phosphorus discharges at the time of writing.
Production specific effluent flows are based on tons paper produced.

It is feasible to reduce phosphorus discharges to below 30 g/ton pulp by optimization of the conventional activated sludge treatment systems presently installed in the three Androscoggin kraft mills, combined with internal mill upgrades to reduce raw waste formation.

Some of these technologies (such as improved mill operating practices and process control in wastewater treatment plants) are relatively inexpensive. Some of the other available phosphorus control technologies are expensive, relative to the normal pulp mill's revenues, but offer environmental advantages beyond phosphorus control, such as reduction in Biological Oxygen Demand (BOD), color and dioxin discharges.

Mills with tertiary treatment systems can operate with phosphorus discharges as low as 10 g/ton, but at relatively high cost. There are very few such systems in the pulp and paper industry worldwide.

The various phosphorus discharge control techniques discussed in the body of the report are summarized in Table 2 , along with indications of the costs for application in Maine conditions.

Table 2 Summary of phosphorus control techniques potentially applicable in Maine

Control measure	Capital cost	Operating cost
Internal measures to reduce discharge of flow and BOD to treatment	Low for modest improvements, high for major improvements	Range from low cost to moderate savings
Optimal design of biological treatment system	Medium in new system High to retrofit	Small increase
Optimal operation of biological treatment system	Nil to low	Probably small saving
Chemical precipitation and separation	Medium	Much higher
Simultaneous precipitation	Low	Much higher

This table presents a simplified summary. Costs refer to an average Maine fiberline with 600 t/day capacity.
Maine mills have already implemented some of the techniques listed.
Refer to the body of report for caveats and basis for data.

The technical content of this report draws heavily on design and mill operating experience in Finland. It is the major pulp and paper producing country in the world with climatic conditions and terrain similar to Maine, which also has a history of successful control of phosphorus discharges from pulp and paper mills.

1.2 Recommendation

Whatever regulation may be developed to reduce the undesirable effects of phosphorus discharges from pulp and paper mills, it is recommended that this be based on the mass flow of phosphorus, rather than as a concentration in the effluent.

2. Introduction

2.1 Terms of reference

N. McCubbin Consultants Inc. (McCubbin) was engaged by the Maine Department of Environmental Protection (MDEP) to assess the current technology available for reduction of phosphorus discharges from the pulp and paper mills in Berlin, New Hampshire, Rumford, ME and Jay, ME The specifications of the work to be performed, defined in McCubbin's contract with MDEP, are as follows:

1 Review the Woodard and Curran, February 19, 2003 report for MeadWestvaco supplied by DEP for its assumptions, conclusions and cost estimates.

2 Provide a review of process controls, treatment, other technologies and costs from other pulp and paper mills similar to those in Maine that achieve phosphorus reduction to levels of 0.25 ppm or as low as possible in the final effluent.

2.2 Background

Mitnik (2003) indicates that a two-thirds reduction of the current discharge of phosphorus by point sources is necessary to approach compliance with water quality criteria in the Androscoggin river.

McCubbin was retained by the Maine DEP in March 2003 to review technical options for achieving this at the major phosphorus sources, the three kraft pulp mills on the river.

2.3 Pulp and paper mills discussed in this report

The technology discussed herein is limited to measures that could potentially be applicable to the three mills of interest, which are listed in Table 3. Since the names of mill owners' change rather frequently, they are referred to in this report by their location.

Table 3 Pulp and paper mills on the Androscoggin River

Town	Company	Pulp St/day	Paper St/day
Berlin, NH (Burgess mill)	Nexfor Fraser Papers Inc.	700	600
Berlin, NH (Cascade mill)	Nexfor Fraser Papers Inc.	0	600
Rumford, ME	Mead Westvaco Inc.	1,050	1,400
Jay, ME	International Paper Inc.	1,000	1,400

.Nexfor does not measure phosphorus discharges from the Cascade paper mill, so the value shown is a rough estimate based on other paper mills. It is small relative to the other mills.

Effluent discharges from the mills that are of interest in this report are summarized in Table 1.

2.3.1 Mill products

All three mills produce bleached chemical pulp using the traditional kraft process with waste liquor recovery, with Elemental Chlorine Free (ECF) bleaching and paper manufacturing on site. In the case of Berlin, the pulp and paper mills have separate water systems and effluent treatment plants. At Rumford and Jay, the pulp and paper mills are integrated.

Precise production data are considered confidential, so only approximations are indicated below.

2.3.2 Berlin mills

There are two mills in Berlin, Burgess and Cascade. The mills are owned and operated by Nexfor Fraser Papers Inc. Each with separate effluent treatment systems and discharges.

The Burgess mill produces approximately 700 t/day kraft pulp, most of which is bleached by an ECF process. Approximately 300 t/day is sold as market pulp and the remainder is used in the Cascade paper mill. The latter produces approximately 600 t/day of a wide variety of papers.

Burgess mill WWTP

The Burgess white water treatment plant (WWTP) consists of a primary clarifier which treats all of the effluent, followed by an activated sludge system, with a single, 72 m (240 ft) diameter, secondary clarifier.

There are two aeration basins in series, with a total retention time of approximately 11 hours at average flow.

Total installed aeration power is 1180 kW (1575 hp)

300 to 450 lbs/day phosphorus is added to maintain nutrient level in the aeration basins.

Phosphorus discharge is normally 2.6 mg/L, at the average flow of approximately 16 MGD (based on 2000 data). The discharge of phosphorus corresponds to a product specific discharge of about 90 g P/ton pulp produced.

Table 4 Actual Average Discharge for Nexfor Fraser Papers Inc, Burgess Mill, Berlin

Parameter	Concentration mg/L	Daily load kg(m3)/d	Product specific load kg (m3)/t pulp
Flow	-	60 000	85
BOD [1)]	29	1750	2.5
TSS [1)]	47	2650	3.8
Total P	2.6	157	0.225

(1) Data from 1998.

Cascade mill WWTP

The Cascade mill WWTP consists of a primary clarifier, which treats all of the effluent, followed by an aerated stabilization basin (ASB).

There is a polishing pond following the aeration basin, with a total retention time of approximately 2 days at average flow of approximately 12 MGD.

Total installed aeration power is 75 kW (100 hp).

There is no addition of phosphorus to the system, but there is some naturally present in the wastewaters. The company does not measure phosphorus discharge.

Table 5 Actual Average Discharge for Nexfor Fraser Papers Inc, Cascade Mill, Berlin

Parameter	Concentration mg/l	Daily load kg(m3)/d	Product specific load kg (m3)/t paper
Flow	-	45 000	63
BOD [1)]	38	1700	2.3
TSS [1)]	21	950	1.4
Total P	NA	NA	NA

(1) Data from 1998.

2.3.3 Rumford mill

The Rumford mill is owned by MeadWestvaco Inc, and produces approximately 700 t/day hardwood pulp and 350 t/day softwood; all of which is bleached by an ECF process. Most of the pulp is used in the paper mill on-site, to produce approximately 1,400 t/day of a variety of coated and uncoated communication grade paper.

The wastewater is treated in an activated sludge treatment plant with an aeration volume of 33500 m3 (8.85 MG) which gives about 7 hours retention time.

The discharge of phosphorus corresponds to a product specific discharge of about 78 g P/ton pulp produced.

Table 6 Actual Average Discharge for MeadWestvaco Inc, Rumford Mill

Parameter	Concentration mg/L	Daily load kg(m3)/d	Product specific load kg (m3)/t pulp
Flow	-	117 000	110
BOD	23	2700	2.5
TSS	32	3800	3.8
Total P	0.7	82	0.078

2.3.4 Jay mill

The Jay mill is owned by International Paper Inc, and produces approximately 1000 t/day hardwood/softwood pulp, all of which is bleached by an ECF process. The pulp is used in the paper mill on-site, to produce approximately 1,400 t/day of a variety of coated and uncoated communication grade paper.

Average untreated BOD discharge is 41000 kg/d (90,000 lb/day).

The WWTP has a conventional primary clarifier, followed by an activated sludge system with two secondary clarifiers, each 76 m (255 ft) diameter, with 4 m (12 ft) sidewall. The aeration tank is a single earthen basin of 120,000 m3 (32 MG) capacity, which corresponds to a hydraulic retention time of approximately 18 hours. There are 55 surface aerators installed, each with 56 kW (75 hp) motors.

Phosphorus is added in the form of a urea-ammonium polyphosphate blend with a P content of ~2.6%. Normal feed is about 750 gallons/day. Mill staff report that they have operated without any phosphorus addition on a trial basis, in anticipation of proposed rules to limit phosphorus discharges. In these cases, the effluent P remained unchanged, but the ortho-P at the aeration basin discharge dropped to levels considered dangerously low by the operators.

The discharge of phosphorus corresponds to a product specific discharge of about 78 g P/ton pulp produced.

Table 7 Actual Average Discharge for International Paper Inc, Jay Mill

Parameter	Concentration mg/L	Daily load kg(m^3)/d	Product specific load kg (m^3)/t pulp
Flow	-	174 000	174
BOD	8	1440	1.4
TSS	33	5730	5.7
Total P	0.8	139	0.139

2.4 Basis for estimating cost of technology upgrades

2.4.1 Perspective

To put the costs discussed in this report in perspective, it is useful to note that a new kraft mill, producing 1,500 tons per day, would probably cost about a billion dollars. The current book value of Maine mills is lower, since they are not new, and are mostly smaller. In recent years, new fiberlines built overseas have 1500 to 2500 t/day capacity. It is generally considered that any new bleached kraft mill must produce at least 1,500 t/day to be economically viable. This is because of the economies of scale inherent in modern, low-pollution, pulp manufacturing equipment. Mill replacement costs in Maine would be in the order of a billion dollars each. Presumably any such dramatic modernization would involve some consolidation of pulp production from a number of smaller sites.

Bleached softwood and hardwood kraft pulps sell today on the open market for $500/ton, which is 5% to 10% higher than a few months ago (FOEX 2003). Prices historically vary over a year by up to $100/ton in response to the normal market pressures of supply and demand. They have been as high as $800/ton, and as low as $400/ton in the past ten years. The impact of a change in operating costs on the viability of a mill can be considered in this context. Future selling prices are unpredictable.

2.4.2 Capital costs

This report includes indications of probable capital costs for various potential process upgrades to reduce phosphorus discharges. They are based on the author's experience and published data. The resources available for this report did not permit visits to each mill, or collection of detailed site specific data, so the costs are generic.

2.4.3 Operating costs

Similar remarks to those above concerning capital costs apply to operating cost estimates. The author assumed that US average prices prevail for raw materials, labor and energy.

2.4.4 Caveat concerning cost estimates

Cost discussed herein are based on those known to have been incurred by other mills, and are presented to indicate probable costs in the Maine mills. They do not take account of all the site-specific construction problems, and any product specific issues that may exist. However, since they are based on actual costs in mills with a range of site-specific problems, producing mainstream products, and the Maine mills are not atypical, the costs are considered to be realistic.

The author recognizes that there are disadvantages in presenting cost estimates without analysis of each mills site-specific situation and historical performance data, but considers that this is much better than ignoring costs in a report of this nature. The capital and operating costs associated with the techniques discussed herein vary from very small to substantial amounts of money, relative to the financial scale of the pulp industry.

Should the Department of Environmental Protection wish to define costs more rigorously, this can be accomplished after inspecting each mill, and considering any data the mill management may wish to present.

3. Pulp and paper manufacturing

3.1 Phosphorus in pulp and paper manufacture

Phosphorus is not used in the pulp and paper manufacturing process, but enters the mill with the wood supply, and other purchased raw materials, principally with the lime or lime-rock (calcium carbonate) used to make-up for losses in the causticizing recycle loop that is a necessary part of the kraft pulp manufacture.

Being an element, phosphorus is neither created not destroyed in the process. Essentially all the phosphorus entering the mill, is discharged with the effluent to the mill's wastewater treatment plant (WWTP).

These treatment systems require phosphorus, if the biological action is to be effective in reducing BOD to the levels normally considered acceptable by regulatory agencies. In practice, the phosphorus concentration in the effluent discharged from a pulp mill is roughly half of that required by the WWTP, so the mills have to add phosphorus to the effluent entering the WWTP.

It is technically feasible, and perhaps economically feasible, to reduce the phosphorus inputs to the mill, but these resulting reduction in phosphorus content of the untreated effluent would simply be replaced by the phosphorus required by the WWTP.

3.2 Phosphorus discharges from kraft pulp and paper mills

The phosphorus discharges from the three mills under discussion are typical of the North American industry. However, a number of mills around the world are required by regulation to limit discharges to much lower values. The performance of some is discussed below. These data demonstrate that operation at lower levels than current in Maine is technically feasible. The mills concerned are profitable, long-term businesses, demonstrating that the performance is economically feasible.

3.2.1 North American mills

Phosphorus discharges by pulp mills have not generally been a major issue in the US, so there is a paucity of readily available data on discharges. Where phosphorus discharges are regulated to low values, it is normally by the State rather than the EPA, so that accessing discharge data requires more personnel time that is available for the present report, although the data are legally public. The following is based on information readily available to the author.

The P H Glatfelter mill at Spring Grove PA is similar to the Androscoggin mill in that it produces a range of papers from both hardwood and softwood kraft pulp manufactured on site. It has long been known in the industry as a low discharge installation, presumably because it is located on very small receiving water. The mill operates with very tight spill control in-plant, and has a conventional activated sludge WWTP. Normal phosphorus discharges are about 0.2 mg/L.

3.2.2 Finland

Many the kraft mills in Finland are located on lakes or rivers whose ecology is phosphorus limited, so much emphasize has been put on reducing phosphorus discharges over the past 10 to 20 years. The climate in Finland is similar to that in Maine (or perhaps colder), so the operating constraints on the treatment plants are similar.

There are no common discharge standards for the pulp and paper mills. There are some general guidelines and overall government decisions but the real control is by an individual discharge permit for each mill. The permit typically includes wastewater discharge limits for TSS, COD, BOD, AOX and phosphorus. The current permits are based on earlier permit levels, current emission levels, recipient status and possible pertinent guidelines.

The discharge limits in current permits are expressed as ton or kilograms per day. There are no concentration based phosphorus limits in the permits. The averaging period may be a single day, one month or one year. For phosphorus, the limit is typically for a monthly averaging period.

The table below presents the phosphorus discharge limits for selected ECF-bleached kraft pulp mills. As seen in the table, the actual discharges are often substantially below the permitted level. The Ennocell mill is well known in Finland for a policy of demonstrating advanced environmental performance to the public.

Table 8 Phosphorus discharge limits for Finnish ECF-bleached kraft pulp mills

Mill	Phosphorus discharge limit		Phosphorus discharge	
	kg P/day	g P/ton pulp	kg P/day	g P/ton pulp
Metsä-Botnia, Joutseno	50	52	29	30
Metsä-Botnia, Kaskinen	50	47	17	16
Stora Enso, Enocell	18	11	5.4	3.3
Sunila, Kotka	35	41	25	30

Discharge data are for 2001. Permit data is current.
Values expressed in g/ton pulp are not in mill permits, but are shown here to facilitate comparison with other mills.

In 2000, the environmental legislation was renewed in line with the EU IPPC-directive (Integrated Pollution Prevention Control). This legislation introduces the concept of “Best Available Techniques[1] and Associated Emission Limits”. Also, the law involves a new integrated approach to permitting, with the intent that a single mill permit will cover all emissions and environmental issues related to the operations at the site.

By the end of 2004 all pulp and paper mills must apply for a new permit according to the new legislation. The permit application process has started for most mills but no new permit has been granted for a pulp mill at the time of writing. However, it is expected that there will be no major changes compared to current permit conditions.

[1] *Although often referred to as “BAT”, the EU concept, and the resulting discharge limitations, recommendations etc. are quite different from “BAT” as the term is defined by US EPA and used routinely in the US.*

In Finland, the first biological wastewater treatment plants in the pulp and paper industry were started–up in the early 1980s. During the following 10 to 15 years practically all pulp and paper mills installed secondary treatment systems. Presently, all but two of the 15 bleached kraft pulp mills have activated sludge treatment systems.

Performance of many of the treatment plants built in the 1980s was poor relative to today's levels. Since many of the wastewater recipients in Finland are small lakes, the environmental impact was not reduced as much as had been hoped. Initially the discharge of nutrients (N, P) from the pulp and paper industry increased as a result of implementation of secondary treatment. In an attempt to improve the situation, many programs were initiated to find methods for optimization of the activated sludge processes and decrease the discharge of nutrients.

The research revealed that the main reasons for poor performance were weaknesses in design of some plants, the lack of effective control of the processes, and deficiencies in the handling of sludge.

The situation regarding the nutrient discharge has improved significantly during the last 10 years, as shown in Figure 1.

The earliest studies carried out at the activated sludge plants revealed poor design especially in the aeration systems and secondary clarifiers. Most of them were upgraded over the next few years.

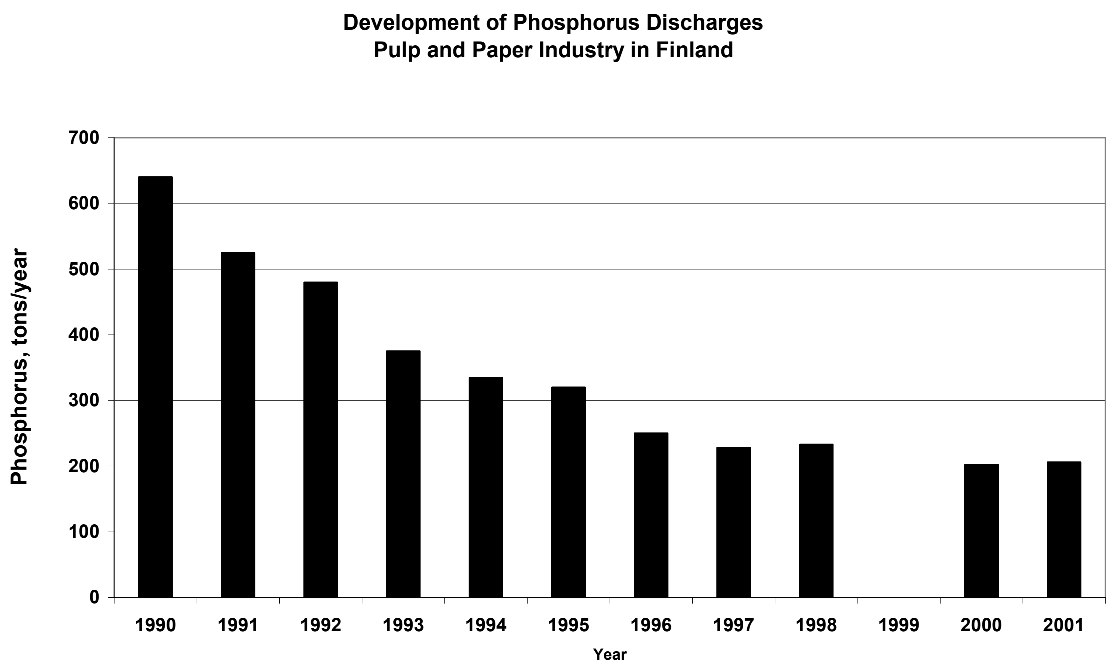

Figure 1 Discharge of Phosphorus from pulp and paper Industry in Finland 1990-2001

In the 1990s, the focus shifted to the control and operation of the plants. By careful control of nutrient dosage and by operating at high sludge ages, a stable discharge of low phosphorus concentration has been achieved at many plants. The dissolved portion of phosphorus is then typically at 0.08 to 0.2 mg P/L.

According to environmental performance statistics from year 1998 the total phosphorus discharges from bleached pulp mills were between 0.08 and 1.1 mg P/L., as shown in Figure 2 and Figure 3.

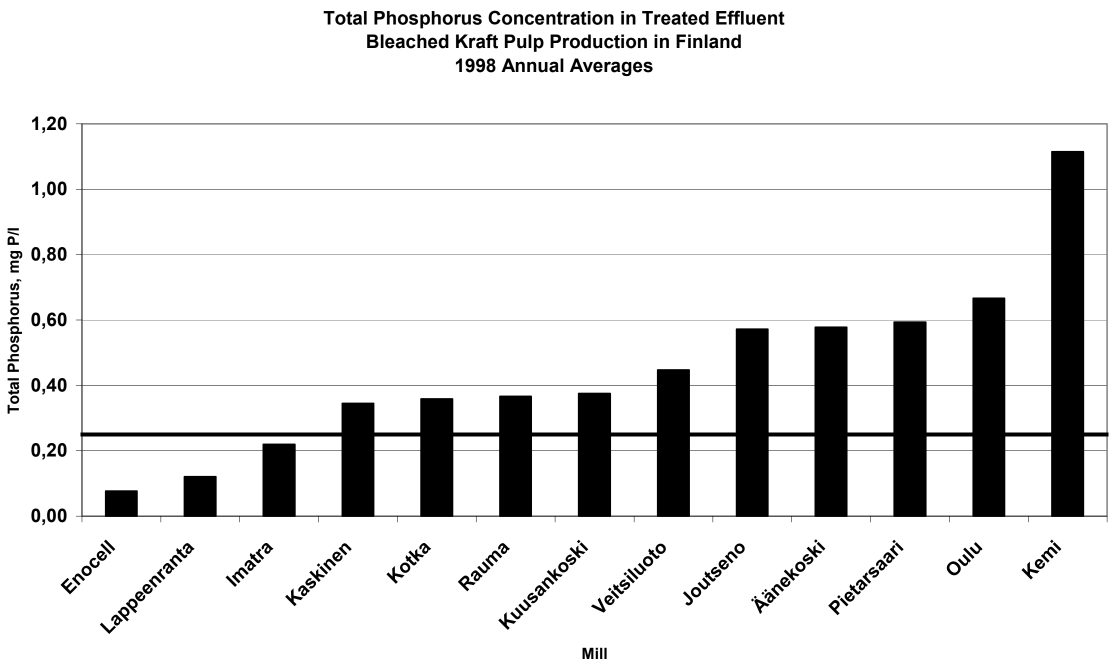

Figure 2 Phosphorus discharge concentrations for bleach kraft pulp mills in Finland

The production facilities of the five best mills can be described briefly as follows:

- Stora Enso, Enocell (Bleached hard and softwood pulp 1600 ton/d);
- UPM-Kymmene, Lappeenranta (Integrated bleached soft and hardwood 1900 t/d, 470 t/d mechanical pulp and 1350 ton/d paper);
- Stora Enso, Imatra (Integrated bleached hard and softwood 1600 t/d, 650 t/d unbleached and CTMP pulp and 2700 ton/d paper and board);
- Metsä-Botnia, Kaskinen (Bleached hard and softwood pulp 1000 ton/d); and
- Sunila, Kotka (Bleached softwood pulp 850 ton/d).

The two best performing mills (Enocell and Lappeenranta) operate without adding any phosphorus to the treatment plants during normal conditions. The residual dissolved phosphorus in the activated sludge process outlet is allowed to drop down to 0.05 to 0.1 mg P/L. Mill staff have advised that no operational problems have been observed due to the low phosphorus levels in the processes. It is noticeable that the COD removal in these treatment plants is amongst the best in Finland.

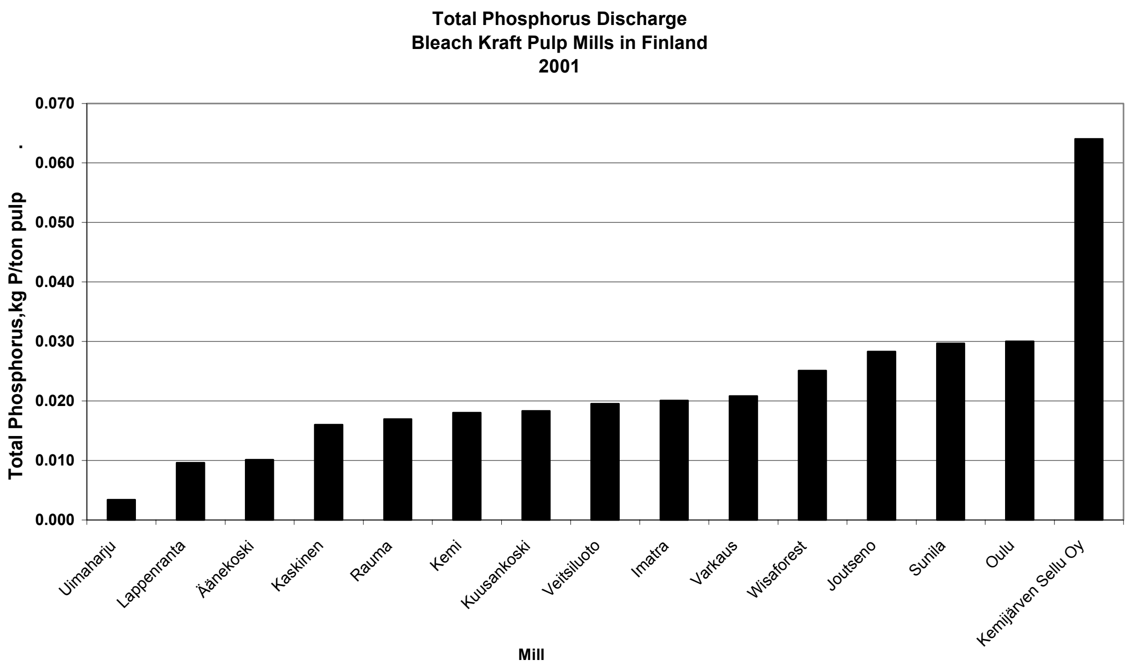

Figure 3 Phosphorus discharges from bleach kraft pulp mills in Finland 2001

3.2.3 European Union

According to the EU directive 96/61/EC, all EU member states must develop their environmental legislation, regulations and permitting procedures in line with the requirements. The directive outlines the concept of Best Available Techniques (BAT), a level of environmental performance that shall be used as a reference level in establishing national regulations, guidelines and individual permits. Each EU member country will incorporate local requirements and conditions into the regulations.

The IPPC-directive stipulates that a Reference Document on Best Available Techniques shall be prepared for each identified branch. Consequently a BAT Reference Document on BAT for the Pulp and Paper Industry has been developed (European Commission 2001).

Chapter 2 of the BAT Reference Document describes the kraft pulping process and specifically the technologies and techniques that are considered BAT, as shown in Table 9.

Table 9 BAT for kraft pulp mills (European concept)

General measures • Training, education and motivation of staff and operators • Process control optimization • Sufficient maintenance of the technical units and the associated abatement techniques • Environmental management systems which optimizes management, increases awareness, and include goals and measures, process and job instructions etc.
Measures for reducing emission to water • Dry debarking of wood • Modified cooking either in batch or continuous system • Highly efficient brown stock washing and closed cycle brown stock screening • Oxygen delignification • ECF bleaching with low AOX or TCF bleaching and recycling of some, mainly alkaline process water from the bleach plant • Stripping and reuse of the condensates from evaporation plant • Effective spill monitoring, containment and recovery system • Sufficient capacity of the black liquor evaporation plant and the recovery boiler to cope with the additional liquor and dry solids load • Collection and reuse of clean cooling waters • For prevention of unnecessary loading and occasional upsets in the external effluent treatment process due to cooking and recovery liquors and dirty condensates, sufficiently large buffer tanks for storage are considered necessary • Primary wastewater treatment • External biological wastewater treatment

Source European Commission (2001).
Although often referred to as "BAT", the EU concept, and the resulting discharge limitations, recommendations etc. are quite different from "BAT" as the term is defined by US EPA and used routinely in the US.

The discharge or consumption levels that are associated with BAT are shown in Table 10 for effluents after primary treatment (i.e. entry to secondary treatment). The corresponding values for effluents after secondary treatment are presented in Table 11. Notice that the phosphorus discharge is reduced across secondary treatment.

Table 10 Emission levels after primary treatment in mills applying BAT

Parameter	Unit	Bleach kraft production
Process water amount	m^3/ ADt	30 – 50
COD	kg/ADt	30 – 45
BOD	kg/ADt	13 – 19
TSS	kg/ADt	2 – 4
AOX	kg/ADt	0 – 0.4
Total P	**kg/ADt**	**0.040 – 0.060**
Total N	kg/ADt	0.3 – 0.4

Source European Commission (2001).

Table 11 Emission levels after biological treatment in mills applying BAT

Parameter	Unit	Bleach kraft production
Process water amount	m^3/ ADt	30 – 50
COD	Kg/ADt	8 – 23
BOD	Kg/ADt	0.3 – 1.5
TSS	Kg/ADt	0.6 – 1.5
AOX	Kg/ADt	0 – 0.25
Total P	**Kg/ADt**	**0.010 – 0.030**
Total N	Kg/ADt	0.1 – 0.25

Source European Commission (2001).

The phosphorus concentration corresponding to BAT Reference Requirements in the tables above is 0.3 to 0.6 mg/L. Notice that the effluent flows are low relative to the Androscoggin River mills.

3.3 Impact of BOD of untreated effluent on phosphorus use and discharge

Biological treatment requires phosphorus for the microbial degradation process that is the essential feature of the process for reducing BOD and COD. In principle, the more BOD that enters the process, the more phosphorus is required. In pulp mill wastewaters, the natural content of phosphorus in influent is usually considered inadequate for optimal treatment, so phosphorus is often added. In an ideal process, virtually all of the naturally incoming and added phosphorus is removed from the wastewaters with the excess sludge, and disposed of or used in an environmentally sound manner. In practice, however, phosphorus is lost with the treated wastewater due to:

- Losses of suspended solids and incorporated biologically bound phosphorus;
- Variations in incoming BOD and P load which result in occasionally elevated dissolved phosphorus (ortho-phosphate); and
- Through flow of biologically “inert” phosphorus.

Variations both in influent quality and internally in the microbiology culture are the major causes for phosphorus control difficulties. Measures for minimizing this cause of phosphorus discharges are discussed below.

4. Phosphorus discharge control in pulp and paper mills

Various process upgrades that can be used to reduce phosphorus discharges in the effluent stream are described below. All are in full-scale commercial service in at least a few mills, and some of the upgrades may have already been implemented in one or more Maine mills.

As in the case of any process upgrade, site-specific engineering analysis is required to define costs and feasibility sufficiently well for a decision to be reached on implementation.

4.1 Overview

The phosphorus present in the wastewater originates from the raw materials and chemicals used in the production process. Some of the phosphorus that is discharged may originate from the addition of phosphorus containing nutrients that are added to enhance the biological process.

In assessing the phosphorus control options, it is important to understand the different forms in which phosphorus may appear. In biologically treated wastewater phosphorus normally exist in soluble phase as ortho or polyphosphates, and in a "solid" phase incorporated with the biological solid matter. The efficiency of control methods is often dependent on the composition of the phosphorus in the wastewater.

Phosphorus cannot be destroyed in a treatment plant, since it is an element. It can be removed by addition of coagulating chemicals, and precipitation or by designing and operating an activated sludge system to maximize the fraction of phosphorus that is retained in the waste sludge.

Whatever sludge is produced must be stored in secure landfill, used beneficially for land improvement or incinerated. In the latter case, the phosphorus in the ash must be controlled to avoid discharge to watercourses.

4.2 Internal process measures to reduce load on WWTP

4.2.1 Water conservation

The wastewater volume has a significant impact on the phosphorus load discharge. Since the addition of nutrients for treatment is often controlled by the residual phosphorus concentration in the treatment plant outlet, higher wastewater volume will normally result in higher phosphorus load discharge.

If the phosphorus limit is defined as a concentration, as proposed in Maine, water conservation may conflict with regulatory compliance. However, from the river's point of view, the concentration is of no importance. The **total load of phosphorus is the critical factor in eutrophication.** It is recommended that any phosphorus discharge regulation that may be developed for pulp and paper mills in Maine be based on a mass flow discharge, rather than on concentration in the effluent.

Water conservation will not only impact on phosphorus discharges but, also positively, on the amount of pollutants discharged from the production systems to treatment, the treatment plant performance, and perhaps most importantly the energy savings.

The three mills involved in the study have all relatively high specific wastewater volume figures, 85, 100 and 174 m^3/t pulp, respectively. For comparison, the average US pulp mill effluent flow is about 90 m^3/t, and Finnish pulp mills discharge between 29 to 64 m^3/t pulp, averaging 48 m^3/t pulp.

The data suggests that the Androscoggin mills have considerable potential to improve their water management. Generally, it is technically straightforward to reduce effluent flow to about 50 m^3/t product. Capital costs are normally in the hundreds of thousands of dollars, and there is normally some reduction in operating costs, due to reduction in treatment costs, and energy savings.

Further reduction of effluent flow usually requires significant investments, and may incur operating costs also.

4.2.2 Reducing BOD of untreated waste waters

In the biological treatment process, organic matter (BOD) is degraded by microbes to carbon dioxide and water. Some of the BOD is used to grow more microbes. Phosphorus has an essential role in the metabolism taking place. Generally you can say that the larger incoming organic load will require more phosphorus for the biochemical reactions and more phosphorus will then leave the plant as well.

Therefore, an important part of phosphorus control is to implement in-mill measures to reduce organic load (BOD) from production. The most important ones are listed in EU BAT Reference document, summarized in Table 9 on page 13.

Lime mud may be a significant source of phosphorus in the wastewater at some mills. Since it is not clear how well the phosphorus present (as $CaPO_4$) can be utilized, excess lime mud should not be sewered but should be recovered dry. Also, discharge of fly ash into sewers may increase phosphorus load.

Since no information has been available regarding mill status or pollutant discharges from the three reviewed pulp mills, no specific measures can be proposed at this point.

4.3 Optimal design of biological treatment system

The optimal design of a biological treatment system is crucial for a good treatment result. The most important objective is to design a system that can absorb and handle normal variations in incoming flow and organic loads and has the capacity to manage occasional spills without causing major disturbances.

It is important that biological systems be designed to maintain stable conditions for the microbiological activity so that the best performing microbes will be selected and dominate in the system.

Treatment process stability is one of the most desired features and requirements to achieve very low discharges. A plant that does not possess the necessary stability features may have their normally very good results spoiled due to occasional poor performance.

The main principles used in the design to achieve stability include:

- Stabilization of influent wastewater flows;
- Prevention and recovery of organic spills, principally black liquor, within the pulp mill;
- Spill pond to divert possible occasional unrecoverable spills;
- Sufficient aeration volume to achieve a high sludge age[2];
- Optimal aeration tank/basin design and aeration type to ensure good quality of micro-organisms (plug flow, selector); and
- Sufficient sludge storage volumes in secondary clarifiers.

In Finland, it can be observed that pulp mills fulfilling these requirements generally have a very high performance level with respect to BOD removal and phosphorus discharge control.

To further reduce pollutants after conventional biological treatment a polishing unit may be used. In Finland there is one pulp mill (Stora Enso, Enocell) operating a large polishing pond or so-

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[2] *The ability of a plant to maintain a high sludge age does not by itself reduce phosphorus discharge. However, high sludge age is normally necessary to allow operators to attain stability and optimal discharge conditions.*

called “Ecological lagoon”. It is effective in reducing BOD and COD in the discharge, and in averaging out variations in effluent characteristics. In the long term, its impact on phosphorus discharges is not significant, although the reduction in short term variations is noticeable. It seems unlikely that such an installation would have a significant effect on the receiving water’s response to phosphorus discharges.

The proper design and operation of sludge handling facilities is very importance as well. In many cases a recirculation load of phosphorus between treatment and sludge handling has been discovered and found to be a cause of high discharges.

In order to reliably assess the potential for improved performance and reduction in phosphorus discharge through treatment process upgrades, a more detailed study should be carried out for each of the three Androscoggin mills.

4.4 Optimal operation of the biological treatment system

To achieve good results, a biological treatment process requires adequate monitoring and control. The operators and personnel need to be trained and educated to understand the implications of data collection and consequences of the various control measures that may be implemented.

4.4.1 Monitoring and control

Process monitoring requires measurements and frequent sampling of the key process-internal streams that indicate the status of the treatment process. If phosphorus concentrations are not measured regularly in the various streams, optimal nutrient addition cannot be attained. It is common practice to simply fix the phosphorus addition rate, normally in excess of what is required to ensure that it will be sufficient for all conditions.

Management of suspended solids is very important in the discharge of phosphorus, and is largely under the operator’s control, presuming that the plant is well designed. Any elevated concentrations of suspended solids will correspondingly increase the concentration of phosphorus in the treated wastewater.

4.4.2 Personnel

Dedicated, knowledgeable and motivated personnel are essential for an optimal operation of the process. We have seen many cases where expensive, well designed plants have been operated by inadequately trained personal with highly unsatisfactory results.

Further, there must be sufficient personnel time allocated for the individuals to perform their assigned work well. The common practice of expecting an individual to operate other major mill systems, such as boilers rarely, if ever, results in optimal performance of the WWTP.

Most, if not all, biological treatment systems in the pulp and paper industry that operate to a high level of performance have at least one full-time professional supervisor who is educated in microbiology, and has sufficient time to continuously investigate the process, and study successful operation in other plants. Certification of a WWTP operator as practiced on many States does not, by itself, represent sufficient education and training, since the technology and practices involved are oriented to municipal wastewaters, which are quite different from pulp mill effluents.

Many of the treatment plants in Finland utilize expert-system based control or advisory system software that supports the operators in their daily assessment of the status of the process.

4.4.3 Phosphorus addition strategies

The most common strategy for control of phosphorus addition in a biological process is to follow the residual ortho-phosphate or dissolved phosphorus concentration. As a general “rule of thumb”, the limiting concentration is often stated to be 0.5 mg P/L. However, as we can see from the results of the best Finnish mills (Enocell and Lappeenranta) a stable process can be operated very low residuals (0.05 to 0.1 mg P/L) and with practically zero addition of phosphorus. Experience from several years of operation reveals no operational problem that can be related to the low phosphorus level. At these mills, phosphorus is added only during shutdown periods.

A common strategy for control of phosphorus addition is to measure influent BOD only and add phosphorus according to a ratio between BOD and P. This strategy is not recommended as a method to achieve low phosphorus levels.

Many of the more advanced control systems utilize an overall approach assessing the phosphorus balance each day thus taking into consideration any accumulation/reduction in the sludge mass.

4.5 Tertiary treatment

Phosphorus in the biologically treated wastewater can be removed by chemical precipitation and separation in a tertiary treatment step. In this treatment process, typically an alum or ferric salt is used to coagulate and precipitate any dissolved phosphorus to a solid phase that can be separated.

Separation of solids may be either by sedimentation or by flotation. Sometimes further removal is accomplished by sand filtration.

In the Nordic countries, tertiary treatment (chemical coagulation) can be found at a number of newsprint mills but only at two kraft pulp mills, one in Finland and one in Sweden. The Finnish mill that has tertiary treatment is an integrated mill producing 500 ton/d softwood and hardwood bleached pulp, 660 ton/d mechanical pulp and 1400 ton/d paper. The wastewater treatment system includes biological treatment in an aerated lagoon and clarification followed by chemical precipitation and flotation as a tertiary step. The start-up on the tertiary treatment was in late

2001 and optimized operation was not reached until late year 2002. Current performance data is summarized in Table 12 below.

Table 12 Performance data of the Finnish kraft pulp mill with tertiary treatment

Parameter	Unit	Total influent	After biological treatment	After tertiary treatment
Flow	m^3/d	60,000	60,000	60,000
TSS	kg/d	41000	2200	2100
Total P	kg/d	50	30	10-15
Total P	mg/L		0.5	0.2 to 0.3

The capital cost of tertiary treatment at the Finnish mill (capacity 60,000 m^3/d) was between two and three million dollars.

In Sweden, the Stora Enso, Skoghall mill operates a treatment system that includes an aerated stabilization basin followed by chemical precipitation. The Skoghall mill is an integrated board mill producing kraft pulp, CTMP and liquid packaging board.

The phosphorus concentration in the treated wastewater at Skoghall mill is about 0.5 mg P/L.

The EU BAT reference document presents a cost estimate of about $US2.6 million for a 700 ton/d pulp mill and $US3.8 million for a 1400 ton/d kraft pulp mill (European Commission 2001).

This same document suggests that the annual operating cost would be in the order of $60,000. The present authors consider that this underestimates thel ikely cost in Maine. Maintenance of the such a system alone would cost approximately this amount. The principal operating cost in tertiary treatment systems is the supply of chemicals. The Woodard report (discussed on page 22) suggests an annual operating cost of several million dollars, but this is based on an unrealistic target for final phosphorus concentration, and on very limited laboratory testing.

The Baikalsk bleached kraft mill in Russia has operated an extremely efficient tertiary treatment system for over 25 years, with phosphorus discharge of 3 g/ton pulp. The chemicals cost approximately a million dollars per year, based on US chemical prices.

However, the annual cost of operating a tertiary treatment system in each of the mills discussed herein would probably be in the order of a million dollars. Tests on each mill effluent would be required to determine the quantities required.

4.6 Simultaneous precipitation

It is not unknown for mills to add coagulants to the secondary clarifier in activated sludge plants, to reduce suspended solids discharges. The International Paper mill at Ticonderoga, NY has described such practices in the open literature, but the author is not aware of any data on the phosphorus content of the effluent.

None of the kraft pulp mills in Finland or in Sweden operates their activated sludge process with addition of coagulation chemicals into the biological process (so-called simultaneous precipitation). However, there are at least a few newsprint mills that do so. In many cases the objective is to enhance COD removal rather than to reduce phosphorus discharges. Dosages are rather small.

The use of simultaneous precipitation is not considered conventional or according to BAT. It is not known to what degree the phosphorus precipitated will be available for the micro-organisms. There is a risk the added phosphorus and coagulant will interact resulting in extra chemical and sludge handling costs.

One of the newsprint mills (1800 ton/d) that operates simultaneous precipitation in a two-stage biological treatment process (submerged biofilter + activated sludge) discharges 0.2 mg P/L as an annual average.

5. The Woodard report

5.1 Brief summary of report

The Woodard report describes the results and conclusions of bench-scale testing of phosphorus removal in the wastewater from the MeadWestwaco, Rumford mill. The objective of the testing was to:

1. Determine approximate ferric chloride dosage required to reduce the phosphorus concentration below 0.25 mg P/L;
2. Determine the amount of sodium hydroxide required to neutralize the mixed liquor after ferric chloride addition; and
3. Estimate annual operating cost associated with ferric chloride addition, caustic addition and sludge disposal costs.

The tests were carried out using the following principal conditions and prerequisites:

- Precipitation is performed with ferric chloride in a sample of mixed liquor to simulate simultaneous precipitation conditions (coagulation chemicals added to the biological process);
- Orthophosphate concentration is adjusted to 0.8 mg/L to simulate the necessary condition required “in the mixed liquor to promote healthy biological growth and flocculation”;
- Total phosphorus is determined from unfiltered and filtered samples. Reactive phosphorus is determined from unfiltered samples; and
- Ferric chloride is added in series up to 250 mg Fe/L.

5.1.1 Conclusions by Woodard:

- 120 mg Fe/L addition will be required to reach the 0.25 mg P/L level but considering day-to-day variability the target should be set at 0.125 mg P/L which corresponds to a dosage of 180 mg Fe/L;
- The mixed liquor suspended solids (MLSS) in the system will increase from 1700 to 2600 mg/L;
- Settling rates in the secondary clarifier will be decreased;
- At a dosage rate of 180 mg Fe/L the annual operating cost will be 4.7 million USD; and
- To guarantee consistent compliance with the 0.25 mg P/L limit, additional tertiary filtration is proposed at an estimated capital cost of 15 to 45 million USD depending on the design conditions and equipment selection.

5.2 Comments to the report conclusions

The basic principle proposed in the report of adding a coagulant/precipitant into the biological process is not a conventional method utilized in the treatment of wastewater from pulp mills. It has been tested in the Nordic countries in small scale but with much smaller quantities and primarily to improve COD reduction. The method cannot be considered proven technology for controlling phosphorus discharges with pulp mill wastewaters.

The high phosphorus removal target results in unrealistically high dosages. Also, when adding ferric chloride into mixed liquor it will not selectively precipitate phosphorus but react with organic compounds as well. This makes the cost-efficiency of the phosphorus removal very low under the conditions proposed. Furthermore, the amount of chemical sludge generated is huge and will most likely strongly interfere with the biological activity.

The prerequisite of maintaining 0.8 mg P/L reactive phosphorus in the wastewater seems out of normal range. The rule of thumb has traditionally been 0.5 mg P/L but much lower levels are maintained at many plants. Some well designed plants in Finland are even operating continuously at a level of 0.05 to 0.1 mg P/L dissolved without any negative consequences for the biological growth.

A capital cost estimate is presented for a tertiary treatment process (filtration with a capacity of about 130,000 m^3/d or 34 MGD). The cost estimate is considerably higher than actual cost of implementing a tertiary flotation unit at a pulp mill in Finland ($2 to 3 million for a capacity of 60,000 m3/d) and also higher than the cost estimates presented by the EU BAT Reference document (European Commission 2001).

6. Measures for phosphorus control in Androscoggin River mills

This study, including international experience of phosphorus control, indicates that there is potential for reduction of the phosphorus discharge by the pulp and paper mills on the Androscoggin River. It also suggests that the cost of improvement and compliance with proposed standards may not be as high as suggested by the Woodard report. However, since very limited data has been made available on an individual mill level, and the budget available for study is quite small, only general comments may be given for each mill at this point. We are confident that a detailed analysis of each mill's WWTP and operations would uncover some low-cost measures for some improvement, and would also provide reliable estimates of the cost of attaining performance equal to that of the best mills in the world.

6.1 Berlin mills

The Berlin Burgess mill has a very high phosphorus discharge (2.6 mg/L) which is not due to extensive losses of suspended solids. It appears that the addition of phosphorus (300 to 450 lb/d) could be considerably reduced. The strategy for the addition of phosphorus is not known.

The relatively large aeration vessel indicates that there may be a potential for achieving relatively high sludge age, which is conducive to a stable process with low phosphorus discharge.

At the Berlin Cascade mill phosphorus is not measured. The first stage at the mill would be to assess their situation regarding phosphorus levels. The installed aeration power is surprisingly low, for a paper mill of this size.

6.2 Rumford mill

Based on the size of the aeration vessel, it appears likely that the treatment plant may be close to its capacity and good phosphorus reduction may be difficult to achieve, unless the volume is increased, or the untreated effluent BOD is reduced.

The BOD of the mill effluent after primary treatment is 70,000 lb/day, equivalent to 25 kg/t paper, or about 35 kg/t pulp. This is higher than one would expect for a mill producing primarily hardwood ECF pulp, suggesting that improvements in brown stock washing, closing the screen process recycle (if not already practiced) and black liquor spill control could reduce the untreated BOD load to below 25 kg/t pulp.

More expensive upgrades, particularly oxygen delignification, would reduce BOD substantially, and also reduce operating costs. However, since the mill has relatively small fiberlines, the reduction in operating costs would not be sufficient to fully justify the capital cost of OD in the normal economic sense.

6.3 Jay mill

The Jay mill has large aeration vessel indicating that there may be a good potential for achieving relatively high sludge age, which will help the operators attain stability in the process with low phosphorus discharge. A rough calculation yields a sludge age of at least 15 days using a MLSS of 3000 mg/L. At this level low phosphorus levels are attainable.

Secondary clarifiers have a hydraulic upflow rate of about 0.8 m/h which is acceptable but does not allow any significant variation in flow.

It is recommended that the mill continue testing without addition of phosphorus for longer period of times even if phosphorus residual concentrations are dropping considerably. (It is not clear what is meant by “dangerously low” concentration in the comment received from the mill staff.)

The mill effluent BOD is approximately 90,000 lb/day prior to primary treatment, which is equivalent to 32 kg/t paper, or 45 kg/t pulp, demonstrating that there is a potential to reduce raw waste loads by well know in-plant pollution prevention measures. This would effectively increase the capacity of the WWTP to operate in a manner that is optimal with respect to phosphorus discharge control. Well known BOD discharge reduction measures include improved brown stock washing, closing the screen process recycle (if not already practiced), black liquor spill control and recovery of paper coating losses. These could reduce the untreated BOD load to below 25 kg/t pulp. It is not practicable to present cost estimates for such measures without detailed study of the mill, but one can observe that they are widely used in profitable mills, so the costs are probably not unreasonable.

More expensive upgrades, particularly modern, two-stage oxygen delignification (OD), would reduce BOD substantially, and also reduce operating costs. However, since the mill has relatively small fiberlines, the reduction in operating costs would not be sufficient to fully justify the capital cost of OD in the normal economic sense.

The reported effluent flow of 37 MGD is equivalent to over 150m^3/t pulp, or 100m^3/t paper. This is well above the US average, and almost ten times the level considered BAT in Europe. This demonstrates that relatively simple measures for reducing effluent flow could be implemented, effectively reducing the upflow rate in the secondary clarifiers, and introducing the margin of safety required to process load variations. The relatively high flow of effluent will result in a low BOD concentration in the WWTP feed, which is not conducive to efficient operation.

A number of US mills operate with untreated BOD discharge rates close to the European BAT values, but their data are considered Confidential Business Information.

7. References

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Unit conversion factors

Unless otherwise stated, all units in this report are stated in the Système International (SI).

Conversion factors between traditional and SI units are shown on the following page.

CONVERSION FACTORS

1 kg (kilogram)	= 2.205 pounds (lb.)	[lb x 0.4536 = kg]
1 t (ton)	= 1.102 short (US) tons	[s. tons x 0.9072 = tons]
1 ADt	= 0.9 oven dry tons pulp	
1 m (metre)	= 3.281 feet	[feet x 0.3048 = m]
1 km (kilometre)	= 0.6214 miles	[miles x 1.609 = km]
1 hectare	= 2.471 acres	[acres x 0.4047 = hectares]
1 km^2	= 100 hectares	
1 km^2	= 0.3861 square miles	[sq. mi. x 2.590 = km^2]
1 L (liter) of water	= approx. 1 kg	
1 m^3 of water	= 1000 L	= approx. 1 ton
	= 35.31 cubic feet	[cubic feet x 0.02832 = m^3]
	= 220.0 Imp. gal.	[Imp. gal. x 0.004546 = $m^{3]}$
	= 264.2 US gal.	[US gal. x 0.003785 = m^3]
1 m^3/t	= 239.7 US gal./short ton	[1000 gal/ton x 4.171 = m^3/t]
1 kg/ton	= 2 lb/short ton	[lb/ton x 0.5000 = kg/t]

Fractional Units

1 ton	(metric ton)	= 10^6 g	= 1000 kg
1 kg	(kilogram)	= 10^3 g	= 1000 g
1 g	(gram)	= 1 g	= 1000 mg
1 mg	(milligram)	= 10^{-3} g	= 1000 µg
1 µg	(microgram)	= 10^{-6} g	= 1000 ng
1 ng	(nanogram)	= 10^{-9} g	= 1000 pg
1 pg	(picogram)	= 10^{-12} g	= 1000 fg
1 fg	(femtogram)	= 10^{-15} g	= 1000 ag
1 ag	(attogram)	= 10^{-18} g	

Approximate Equivalents

1 g/L	= 1 g/kg	= 10^{-3} g/g	= "1 part per thousand"	
1 mg/L	= 1 mg/kg	= 10^{-6} g/g	= "1 part per million"	ppm
1 µg/L	= 1 µg/kg	= 10^{-9} g/g	= "1 part per billion"	ppb
1 ng/L	= 1 ng/kg	= 10^{-12} g/g	= "1 part per trillion"	ppt
1 pg/L	= 1 pg/kg	= 10^{-15} g/g	= "1 part per quadrillion"	ppq